

# Adaptive Distributed Space-Time Coding in Cooperative MIMO Relaying Systems using Limited Feedback

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**Abstract**—An adaptive randomized distributed space-time coding (DSTC) scheme is proposed for two-hop cooperative MIMO networks. Linear minimum mean square error (MMSE) receiver filters and randomized matrices subject to a power constraint are considered with an amplify-and-forward (AF) cooperation strategy. In the proposed DSTC scheme, a randomized matrix obtained by a feedback channel is employed to transform the space-time coded matrix at the relay node. The effect of the limited feedback and feedback errors are considered. Linear MMSE expressions are devised to compute the parameters of the adaptive randomized matrix and the linear receive filters. A stochastic gradient algorithm is also developed with reduced computational complexity. The simulation results show that the proposed algorithms obtain significant performance gains as compared to existing DSTC schemes.

## I. INTRODUCTION

Cooperative multiple-input and multiple-output (MIMO) systems, which employ multiple relay nodes with antennas between the source node and the destination node as a distributed antenna array, apply distributed diversity gain and provide copies of the transmitted signals to improve the reliability of wireless communication systems [12]. Among the links between the relay nodes and the destination node, cooperation strategies, such as Amplify-and-Forward (AF), Decode-and-Forward (DF), and Compress-and-Forward (CF) [1] and various distributed space-time coding (DSTC) schemes in [2], [3] and [19] can be employed.

The utilization of a distributed STC (DSTC) at the relay node in a cooperative network, providing more copies of the desired symbols at the destination node, can offer the system diversity gains and coding gains to combat the interference. The recent focus on the DSTC technique lies in the design of delay-tolerant codes and full-diversity schemes with minimum outage probability. An opportunistic DSTC scheme with the minimum outage probability is designed for a DF cooperative network and compared with the fixed DSTC schemes in [4]. An adaptive distributed-Alamouti (D-Alamouti) STBC design is proposed in [5] for non-regenerative dual-hop wireless systems which achieves the minimum outage probability.

The channel state information (CSI) is very important for a wireless communication system and can be estimated by sending a block of training symbols to the destination node. The feedback technique allows the destination node to transmit the CSI or other information back to the source node, in order to achieve gains by pre-processing the symbols. In [6], the trade-off between the length of the feedback symbols, which

is related to the capacity loss, and the transmission rate is discussed, and in [7], one solution for this trade-off problem is derived. The use of limited feedback for STC encoding has been widely discussed in the literature. In [8], the phase information is sent back for STC encoding in order to maintain the full diversity, and the phase feedback is employed in [9] to improve the performance of the Alamouti STBC. The limited feedback is used in [10] and [11] to provide the channel information for the pre-coding of an OSTBC scheme.

In this paper, we propose an adaptive linear receiver design algorithm with randomized distributed space-time coding optimization based on the MSE criterion for cooperative MIMO relaying systems with limited feedback. We focus on how the randomized matrix affects the DSTC during the encoding and how to optimize the linear receive filter with the randomized matrix iteratively. It is shown that the utilization of a randomized matrix benefits the performance of the system compared to using traditional STC schemes. Then an adaptive optimization algorithm is derived based on the MSE criterion subject to constraints on the transmitted power at the relays, with the aid of a stochastic gradient (SG) algorithm in order to release the destination node from the high computing complexity of the optimization process. The updated randomized matrix is transmitted to the relay node through a feedback channel with errors, and the influence of the imperfect feedback is discussed.

The paper is organized as follows. Section II introduces a two-hop cooperative MIMO system with multiple relays applying the AF strategy and the randomized DSTC scheme. In Section III the proposed optimization algorithm for the randomized matrix is derived, and the results of the simulations are given in Section IV and Section V leads to the conclusion.

## II. COOPERATIVE SYSTEM MODEL

The communication system under consideration, shown in Fig.1, is a cooperative communication system employing multi-antenna relay nodes transmitting through a MIMO channel from the source node to the destination node with feedback channels to the relay nodes. The 4-QAM modulation scheme is used in our system to generate the transmitted symbol vector  $s[i]$  at the source node. There are  $n_r$  relay nodes with  $N$  antennas for transmitting and receiving, applying an AF cooperative strategy as well as a DSTC scheme, between the source node and the destination node. A two-hop communication system that broadcasts symbols from the source to  $n_r$  relay nodes as

well as to the destination node in the first phase, followed by transmitting the amplified and re-encoded symbols from each relay node to the destination node in the next phase. After decoding at the destination node, the information matrix for encoding will be quantized first, and then transmitted back to each relay node through a feedback channel with noise and interference. The relay nodes quantize the feedback symbols and use them as a part of the encoding matrix in the next transmission. We consider only one user at the source node in our system that has  $N$  Spatial Multiplexing (SM)-organized data symbols contained in each packet. The received symbols at the  $k$ -th relay node and the destination node are denoted as  $\mathbf{r}_{SR_k}$  and  $\mathbf{r}_{SD}$ , respectively, where  $k = 1, 2, \dots, n_r$ . The received symbols  $\mathbf{r}_{SR_k}$  will be amplified before mapped into an STC matrix. We assume that the synchronization at each node is perfect. The received symbols at the destination node and each relay node can be described as follows

$$\mathbf{r}_{SR_k}[i] = \mathbf{F}_k[i]\mathbf{s}[i] + \mathbf{n}_{SR_k}[i], \quad (1)$$

$$\mathbf{r}_{SD}[i] = \mathbf{H}[i]\mathbf{s}[i] + \mathbf{n}_{SD}[i], \quad (2)$$

$$i = 1, 2, \dots, N, \quad k = 1, 2, \dots, n_r,$$

where the  $N \times 1$  vector  $\mathbf{n}_{SR_k}[i]$  and  $\mathbf{n}_{SD}[i]$  denote the zero mean complex circular symmetric additive white Gaussian noise (AWGN) vector generated at each relay and the destination node with variance  $\sigma^2$ . The transmitted symbol vector  $\mathbf{s}[i]$  contains  $N$  parameters,  $\mathbf{s}[i] = [s_1[i], s_2[i], \dots, s_N[i]]$ , which has a covariance matrix  $E[\mathbf{s}[i]\mathbf{s}^H[i]] = \sigma_s^2 \mathbf{I}$ , where  $E[\cdot]$  stands for expected value,  $(\cdot)^H$  denotes the Hermitian operator,  $\sigma_s^2$  is the signal power which we assume to be equal to 1 and  $\mathbf{I}$  is the identity matrix.  $\mathbf{F}_k[i]$  and  $\mathbf{H}[i]$  are the  $N \times N$  channel gain matrices between the source node and the  $k$ -th relay node, and between the source node and the destination node, respectively.

After processing and amplifying the received vector  $\mathbf{r}_{SR_k}[i]$  at the  $k$ -th relay node, the signal vector  $\tilde{\mathbf{s}}_{SR_k}[i] = \mathbf{A}_{R_k D}[i](\mathbf{F}_k[i]\mathbf{s}[i] + \mathbf{n}_{SR_k}[i])$  can be obtained and will be forwarded to the destination node. The amplified symbols in  $\tilde{\mathbf{s}}_{SR_k}[i]$  will be re-encoded by an  $N \times T$  DSTC scheme  $\mathbf{M}(\tilde{\mathbf{s}}[i])$  and then multiplied by an  $N \times N$  randomized matrix  $\mathfrak{R}[i]$  in [20], then forwarded to the destination node. The relationship between the  $k$ -th relay and the destination node can be described as

$$\mathbf{R}_{R_k D}[i] = \mathbf{G}_k[i]\mathfrak{R}[i]\mathbf{M}_{R_k D}[i] + \mathbf{N}_{R_k D}[i], \quad (3)$$

$$k = 1, 2, \dots, n_r,$$

where the  $N \times T$  matrix  $\mathbf{M}_{R_k D}[i]$  is the DSTC matrix employed at the relay nodes whose elements are the amplified symbols in  $\tilde{\mathbf{s}}_{SR_k}[i]$ . The  $N \times T$  received symbol matrix  $\mathbf{R}_{R_k D}[i]$  in (3) can be written as an  $NT \times 1$  vector  $\mathbf{r}_{R_k D}[i]$  given by

$$\mathbf{r}_{R_k D}[i] = \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{G}_{eq_{kj}}[i] \tilde{\mathbf{s}}_{SR_k j}[i] + \mathbf{n}_{R_k D}[i], \quad (4)$$

where the  $NT \times N$  matrix  $\mathbf{G}_{eq_{kj}}[i]$  stands for the equivalent channel matrix which is the DSTC scheme  $\mathbf{M}(\tilde{\mathbf{s}}[i])$  combined with the channel matrix  $\mathbf{G}_{R_k D}[i]$  and the block diagonal  $NT \times NT$  matrix  $\mathfrak{R}_{eq_{kj}}[i]$  denotes the equivalent randomized

matrix assigned for the  $j$ -th forwarded symbol at the relay node. The  $NT \times 1$  equivalent noise vector  $\mathbf{n}_{R_k D}[i]$  generated at the destination node contains the noise parameters in  $\mathbf{N}_{R_k D}[i]$ . After rewriting  $\mathbf{R}_{R_k D}[i]$  we can consider the received symbol vector at the destination node as a  $N(n_r + 1)$  vector with two parts, one is from the source node and another one is the superposition of the received vectors from each relay node, therefore the received symbol vector for the cooperative MIMO network we considered can be written as

$$\begin{aligned} \mathbf{r}[i] &= \begin{bmatrix} \sum_{j=1}^N \mathbf{H}_{eq_j}[i] s_j[i] \\ \sum_{k=1}^{n_r} \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{G}_{eq_{kj}}[i] \tilde{\mathbf{s}}_{SR_k j}[i] \end{bmatrix} \\ &\quad + \begin{bmatrix} \mathbf{n}_{SD}[i] \\ \mathbf{n}_{RD}[i] \end{bmatrix} \\ &= \sum_{j=1}^N \mathbf{D}_{D_j}[i] \tilde{\mathbf{s}}_{D_j}[i] + \mathbf{n}_D[i], \end{aligned} \quad (5)$$

where the  $(T+1)N \times (n_r+1)N$  block diagonal matrix  $\mathbf{D}_{D_j}[i]$  denotes the channel gain matrix of all the links in the network for the  $j$ -th symbol in  $\tilde{\mathbf{s}}_{D_j}[i]$  which contains the  $N \times N$  channel coefficients matrix  $\mathbf{H}[i]$  between the source node and the destination node, the  $NT \times N$  equivalent channel matrix  $\mathbf{G}_{eq_k}[i]$  for  $k = 1, 2, \dots, n_r$  between each relay node and the destination node. The  $(n_r+1)N \times 1$  noise vector  $\mathbf{n}_D[i]$  contains the received noise vector at the destination node and the amplified noise vectors from each relay node, which can be derived as an AWGN with zero mean and covariance matrix  $\sigma^2(1 + \|\mathfrak{R}_{eq_k}[i] \mathbf{G}_{eq_k}[i] \mathbf{A}_{R_k D}[i]\|_F^2) \mathbf{I}$ , where  $\|\mathbf{X}\|_F = \sqrt{\text{Tr}(\mathbf{X}^H \cdot \mathbf{X})} = \sqrt{\text{Tr}(\mathbf{X} \cdot \mathbf{X}^H)}$  stands for the Frobenius norm.

### III. JOINT CONSTRAINED ADAPTIVE RANDOMIZED STC OPTIMIZATION AND LINEAR MMSE RECEIVER DESIGN

As derived in the previous section, the DSTC scheme used at the relay node will be multiplied by a randomized matrix subject to a power constraint before being forwarded to the destination node. In this section, we design a constrained adaptive optimization algorithm based on an SG estimation algorithm [18] for determining the optimal randomized matrix and the linear MMSE receive filters.

#### A. Linear MMSE Receiver Design with RSTC Optimization

The linear MMSE receiver design and the optimal RSTC matrices subject to a transmit power constraint at the relays are derived as follows. Define the  $(T+1)N \times 1$  parameter vector  $\mathbf{w}_j[i]$  to determine the  $j$ -th symbol  $s_j[i]$ . From (5) we propose the MSE based optimization with a power constraint at the destination node as

$$[\mathbf{w}_j[i], \mathfrak{R}_{eq_{kj}}[i]] = \arg \min_{\mathbf{w}_j[i], \mathfrak{R}_{eq_{kj}}[i]} E[\|\mathbf{s}_j[i] - \mathbf{w}_j^H[i] \mathbf{r}[i]\|^2],$$

subject to

$$\sum_{j=1}^N \text{trace}(\mathfrak{R}_{eq_{kj}}[i] \mathfrak{R}_{eq_{kj}}^H[i]) \leq P_R,$$

where  $\mathbf{r}[i]$  denotes the received symbol vector at the destination node which contains the randomized STC matrix with the power constraint of  $P_R$ . If we only consider the received

symbols from the relay node, the received symbol vector at the destination node can be derived as

$$\begin{aligned}
\mathbf{r}[i] &= \sum_{k=1}^{n_r} \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{G}_{eq_{kj}}[i] \tilde{\mathbf{s}}_{SR_{kj}}[i] + \mathbf{n}_D[i] \\
&= \sum_{k=1}^{n_r} \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{G}_{eq_{kj}}[i] \mathbf{A}_j[i] \mathbf{F}_j[i] s_j[i] \\
&\quad + \sum_{k=1}^{n_r} \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{G}_{eq_{kj}}[i] \mathbf{A}_j[i] n_{SR_j}[i] \\
&\quad + \mathbf{n}_{RD}[i] \\
&= \sum_{k=1}^{n_r} \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{C}_{kj}[i] s_j[i] + \mathbf{n}_{Deq}[i],
\end{aligned} \tag{6}$$

where  $\mathbf{C}_{kj}[i]$  is an  $NT \times N$  matrix that contains all the complex channel gains and the amplified matrix assigned to the received symbol  $s_j[i]$  at the relay node, and the noise vector  $\mathbf{n}_{Deq}[i]$  is a Gaussian noise vector with zero mean and variance  $\sigma^2(1 + \sum_{k=1}^{n_r} \|\mathfrak{R}_{eq_{kj}}[i] \mathbf{G}_{eq_{kj}}[i] \mathbf{A}_j[i]\|_F^2)$ . Therefore, we can rewrite the MSE cost function as in (7).

Since  $\mathbf{w}_j[i]$  can be optimized by expanding the righthand side of (7) and taking the gradient with respect to  $\mathbf{w}_j^*[i]$  and equating the terms to zero, we can obtain the  $j$ -th MMSE receive filter

$$\mathbf{w}_j[i] = (E[\mathbf{r}[i] \mathbf{r}^H[i]])^{-1} E[\mathbf{r}[i] s_j^H[i]], \tag{8}$$

where  $E[\mathbf{r}[i] \mathbf{r}^H[i]]$  denotes the auto-correlation matrix and  $E[\mathbf{r}[i] s_j^H[i]]$  stands for the cross-correlation matrix. By optimizing the randomized matrix  $\mathfrak{R}_{eq_{kj}}[i]$  for each symbol at each relay node, we can first define a vector  $\tilde{\mathbf{r}}_{eq_{kj}} = \mathbf{C}_{kj}[i] s_j[i] + \mathbf{C}_{kj}[i] n_{SR_j}$ , where the parameter  $n_{SR_j}$  denotes the  $j$ -th symbol in the noise vector  $\mathbf{n}_{SR}$ , then the randomized matrix can be calculated by taking the gradient with respect to  $\mathfrak{R}_{eq_{kj}}^*[i]$  and equating the term to zero, resulting in

$$\begin{aligned}
\mathfrak{R}_{eq_{kj}}[i] &= (\mathbf{w}_j^H[i] (E[\tilde{\mathbf{r}}[i] \tilde{\mathbf{r}}^H[i]]) \mathbf{w}_j[i] + \lambda \mathbf{I})^{-1} \\
&\quad E[\tilde{\mathbf{r}}^H[i] s_j[i]] \mathbf{w}_j[i],
\end{aligned} \tag{9}$$

where  $E[\tilde{\mathbf{r}}[i] \tilde{\mathbf{r}}^H[i]]$  denotes the auto-correlation matrix of the equivalent space-time coded received symbol vector without the randomized matrix at the relay node, and  $E[\tilde{\mathbf{r}}^H[i] s_j[i]]$  denotes the cross-correlation matrix. The power constraint can be achieved by multiplying the quotient of  $P_R$  and the trace of the updated randomized matrix. The expression in (9) does not provide a closed-form solution of the randomized STC matrix  $\mathfrak{R}_{eq_{kj}}[i]$  assigned for the  $j$ -th received symbol at the  $k$ -th relay node because it requires the adjustment of the Lagrange multiplier  $\lambda$ . This parameter needs to be adjusted in order to enforce the power constraint. Moreover, the expression in (9) also requires an inversion calculation with a high computational complexity. With the increase of the number of antennas employed at each node or employing more complicated STC encoders at the relay nodes, the complexity increases exponentially according to the matrix size in (9).

## B. Adaptive Linear MMSE Receiver Design with Randomized Matrix Optimization Algorithm

In order to reduce the computational complexity of the proposed design and compute the required parameters, an adaptive linear receiver design with randomized matrix optimization (ALRRMO) algorithm is proposed. We resort to a strategy that initially drops the power constraint, obtain the necessary recursions and then enforce the constraint with a normalization step. We define the Lagrangian of the constrained MSE minimization problem in (7) as

$$\begin{aligned}
\mathcal{L}(\mathbf{w}_j[i], \mathfrak{R}_{eq_{kj}}[i]) &= E[\|s_j[i] - \mathbf{w}_j^H[i] \mathbf{r}[i]\|^2] \\
&\quad + \left( \sum_{j=1}^N \text{trace}(\mathfrak{R}_{eq_{kj}}[i] \mathfrak{R}_{eq_{kj}}^H[i]) - P_R \right) \lambda,
\end{aligned} \tag{10}$$

A simple adaptive algorithm for determining the linear receive filters and the randomized matrices can be achieved by taking the instantaneous gradient term of (7) with respect to  $\mathbf{w}_j^*[i]$  and with respect to  $\mathfrak{R}_{eq_{kj}}^*[i]$ , respectively, which are

$$\begin{aligned}
\nabla \mathcal{L} \mathbf{w}_j^*[i] &= \nabla E[\|s_j[i] - \mathbf{w}_j^H[i] \mathbf{r}[i]\|^2] \mathbf{w}_j^*[i] \\
&= -(s_j[i] - \mathbf{w}_j^H[i] \mathbf{r}[i])^H \mathbf{r}[i] = -e_j^*[i] \mathbf{r}[i], \\
\nabla \mathcal{L} \mathfrak{R}_{eq_{kj}}^*[i] &= \nabla E[\|s_j[i] - \mathbf{w}_j^H[i] \mathbf{r}[i]\|^2] \mathfrak{R}_{eq_{kj}}^*[i] \\
&= -e_j[i] s_j^H[i] \mathbf{C}_{kj}^H[i] \mathbf{w}_j[i],
\end{aligned} \tag{11}$$

where  $e_j[i]$  stands for the  $j$ -th detected error. After we obtain (11) the proposed algorithm is obtained by introducing a step size into the recursions. The proposed algorithm is given by

$$\begin{aligned}
\mathbf{w}_j[i+1] &= \mathbf{w}_j[i] + \beta (e_j^*[i] \mathbf{r}[i]), \\
\mathfrak{R}_{eq_{kj}}[i+1] &= \mathfrak{R}_{eq_{kj}}[i] + \mu (e_j[i] s_j^H[i] \mathbf{C}_{kj}^H[i] \mathbf{w}_j[i]), \\
\mathfrak{R}_{eq_{kj}}[i+1] &= \frac{\sqrt{P_R} \mathfrak{R}_{eq_{kj}}[i+1]}{\sqrt{\sum_{j=1}^N \text{trace}(\mathfrak{R}_{eq_{kj}}[i+1] \mathfrak{R}_{eq_{kj}}^H[i+1])}},
\end{aligned} \tag{12}$$

where  $\beta$  and  $\mu$  denote the step sizes for the recursions for the estimation of the linear MMSE receive filter and the randomized matrix in the RSTC scheme, respectively. The last equation in (12) stands for the normalization of the randomized matrix after the iteration. According to (12), the desired vector and the matrix depends on each other, so that the algorithm in [17] can be used to determine the linear MMSE receive filter and the randomized matrix iteratively, and the design can be achieved. The complexity for calculating the optimal  $\mathbf{w}_j[i]$  and  $\mathfrak{R}_{eq_{kj}}[i]$  is  $O(N(T+1))$  and  $O(N^2 T^2)$ , respectively, which is much less than  $O(2N^3(T+1)^3)$  and  $O(2N^4 T^4)$  by using (8) and (9). As mentioned in Section I, the randomized matrix will be sent back to the relay nodes via a feedback channel which requires quantization as will be shown in the simulations.

## IV. SIMULATIONS

The simulation results are shown here to assess the proposed scheme and algorithm. The system we considered is an AF cooperative MIMO system with the Alamouti STBC scheme using QPSK modulation in quasi-static block fading channel with AWGN, as derived in Section II. The bit error rate

$$[\mathbf{w}_j[i], \mathfrak{R}_{eq_{kj}}[i]] = \arg \min_{\mathbf{w}_j[i], \mathfrak{R}_{eq_{kj}}[i]} E \left[ \left\| s_j[i] - \mathbf{w}_j^H[i] \left( \sum_{k=1}^{n_r} \sum_{j=1}^N \mathfrak{R}_{eq_{kj}}[i] \mathbf{C}_{kj}[i] s_j[i] + \mathbf{n}_D[i] \right) \right\|^2 \right], \quad s.t. \quad \sum_{j=1}^N \text{trace}(\mathfrak{R}_{eq_{kj}}[i] \mathfrak{R}_{eq_{kj}}^H[i]) \leq P_R. \quad (7)$$

(BER) performance of the proposed adaptive linear receiver design with RSTC optimization algorithm is assessed, and the influence of the imperfect feedback channels are considered in the simulations. The system employs 1 relay node and each node in the system has 2 antennas. In the simulation, we define both the symbol power at the source node and the noise variance  $\sigma^2$  for each link to be equal to 1. The RSTC scheme is designed by multiplying the  $2 \times 2$  Alamouti STBC [15] by a randomized matrix with each element generated using  $e^{j\theta}$  where  $\theta$  is uniformly distributed in  $[0, 2\pi)$ .

The proposed ALRRMO algorithm is compared with the SM scheme and the traditional RSTC algorithm using the distributed-Alamouti (D-Alamouti) STBC scheme in [19] with  $n_r = 1$  relay nodes in Fig. 2. The number of antennas  $N = 2$  at each node and the effect of the direct link is considered. The results illustrate that without the direct link, by making use of the STC or the RSTC technique, a significant performance improvement can be achieved compared to the spatial multiplexing system. The RSTC algorithm outperforms the STC-AF system, while the ALRRMO algorithm can improve the performance by about 3dB as compared to the RSTC algorithm. With the consideration of the direct link, the results indicate that the cooperative diversity order can be increased, and using the ALRRMO algorithm achieves an improved performance with 2dB of gain as compared to employing the RSTC algorithm and 3dB of gain as compared to employing the traditional STC-AF algorithm.

The simulation results shown in Fig. 3 illustrate the impact of the feedback channel for the ALRRMO algorithm. As mentioned in Section I, the optimal randomized matrix will be sent back to each relay node through a feedback channel. The quantization and feedback errors are not considered in the simulation results in Fig. 2, so the optimal randomized matrix is perfectly known at the relay node after the ALRRMO algorithm; while in Fig. 3, it indicates that the performance of the proposed algorithm will be affected by the accuracy of the feedback information. In the simulation, we use 4 bits to quantize the real part and the imaginary part of each element of the randomized matrix  $\mathfrak{R}_{eq_{kj}}[i]$ , and the feedback channel is a binary symmetric channel. As we can see from Fig. 3, by decreasing the error probabilities for the feedback channel with fixed quantization bits, the BER performance approaches the performance with the perfect feedback, and by making use of 4 quantization bits for the real and imaginary part of each parameter in the randomized matrix, the performance of the ALRRMO algorithm is about 1dB worse with feedback error probability of  $10^{-3}$ .

In Fig. 4 and Fig. 5, the influence of different feedback error probabilities with various quantization bits are employed to test the performance of the ALRRMO algorithm. In Fig. 4, the BER performance with a perfect feedback channel is given as a lower bound with  $SNR = 15dB$  and  $SNR = 30dB$ , respectively. The error probability is fixed in  $P_e = 10^{-3}$ . With the increase of the number of bits we employed in the

quantization, the BER curves will approach the result with perfect feedback due to a more accurate estimation with the cost of computing complexity increase. With more quantization bits, the ALRRMO algorithm can achieve a performance as good as that with perfect feedback. However, it is worth to mention that the BER decreases slightly when we increase the number of quantization bits to 5 and 6. If we fix the number of quantization bits to 4, the BER performance gets worse with the increase of the feedback error probability as depicted in Fig.5. By increasing the feedback error probability, the BER curves become gradually worse. Thus, there is a trade-off between the feedback error probability and the number of quantization bits. As indicated by the simulation results in Fig. 3 to Fig. 5, the 4-bit quantization is an appropriate choice.

## V. CONCLUSION

We have proposed an adaptive linear receiver filter design with randomized matrix optimization (ALRRMO) algorithm for the randomized DSTC in a cooperative system. A joint iterative estimation algorithm for computing the receive filters and the randomized matrix has been derived. The effect of the limited feedback and feedback errors are considered in the simulation. The simulation results illustrate the advantage of the proposed ALRRMO algorithm by comparing it with the cooperative network employing the traditional DSTC scheme and the fixed randomized STC scheme. The proposed algorithm can be used with different distributed STC schemes using the AF strategy and can also be extended to the DF cooperation protocol.

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